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DOCUMENTATION OF LIGHTNING DISCHARGES AND RESULTANT FOREST FIRES

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ABSTRACT

Characteristics of lightning discharge and observed lightning effects were studied to determine whether a specific type of discharge causes ignition of forest fuels. Discharge characteristics, including return stroke type, magnitude, and duration, were recorded from the output of electric field change sensors at ground stations, while the discharges and their respective ground terminals (e.g., trees) were observed from a nearby aircraft. Seven discharges that caused forest fires were documented during four storms in 1965 and 1966. Evidence that all seven discharges had a long-continuing current phase supports the hypothesis that this type of discharge causes forest fires.

Lightning causes some 10,000 forest and range fires each year in the United States, but these fires probably represent only a small fraction of the total number of cloud-to-ground discharges occurring in that area during a year. The apparent inefficiency of lightning in igniting fires has given rise to the hypothesis that fires are caused by a particular type of discharge. McEachron and Hagenguth[2] proposed that discharges that ignite forest fuels usually have a long-continuing current phase. This

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[2]McEachron, K. B., and J. H. Hagenguth. Effect of lightning on thin metal surfaces, AIEE Trans. 61: 559-564. 1942.

view resulted from work with laboratory sparks and from examination of lightning effects. Although the theory is widely accepted today,[3 4 5] the only known field corroboration to date was that reported by Norinder et al.,[6] who found that each of two discharges causing fire in Sweden had a long-continuing current phase. Using the methods described below, we have recently documented characteristics of seven lightning discharges that caused forest fires in western Montana.

METHODS

Discharge characteristics, including return stroke type, magnitude, luminosity, and duration, were recorded at ground-based recording stations. The sensors were fast and slow electric field change meters and a nondirectional luminosity device. The output of the sensors was recorded on a 7-channel tape recorder and retrieved later for analysis on a 14-channel oscillograph. The fast and slow field change sensors are identical, with the exception of the grid resistor in the electrometer stage. The grid resistor establishes the sensor time constant, which is 5 msec. for the fast antenna and 5 sec. for the slow antenna. The field change sensor circuit consists essentially of a flat-plate antenna, an electrometer stage, an emitter follower, and an amplifier. The output is directly proportional to the change in field at the antenna. The luminosity measuring system consists of a cone-shaped mirror and a parabolic mirror with an uncooled lead sulfide detector at the focal point. The detector is capacitor coupled to an output amplifier stage. The system has a 5-msec. time constant that corresponds to the fast field change meter.

The electric field change due to a lightning stroke measured at the surface of the earth can be given by the following equation[7] based on a simple positive dipole model:

$$\Delta E = 90 \frac{2Q_r H_r}{\left(D^2 + H_r^{\,2}\right)^{3/2}}$$

where ΔE is in volts/centimeter, Q_r is in coulombs, and H_r and D are in kilometers.

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[3]Berger, K. Lightning research in Switzerland. Weather 2(3): 231-238. 1947.

[4]Malan, D. J. Physics of lightning, 176 pp., London: English Universities Press Limited. 1963.

[5]Loeb, Leonard B. The mechanisms of stepped and dart leaders in cloud-to-ground lightning strokes. J. Geophys. Res. 71(20): 4711-4721. 1966.

[6]Norinder, H., Knudsen, E., and Vollmer, B. Multiple strokes in lightning channels. In: Recent Advances in Atmospheric Electricity, pp. 525-542. New York: Pergamon Press. 1958.

[7]Brook, M. Kitagawa, N., and Workman, E. J. Quantitative study of strokes and continuing currents in lightning discharges to ground. J. Geophys. Res. 67(2): 649-659.

Here D is the horizontal distance from the field meter to the discharge, and H_r is the vertical height to the assumed center of Charge Q_r.

We measured the electric field change (ΔE) at two stations in 1965 and at four stations in 1966. The approximate horizontal distance (D) was found by aircraft observation. This information was then used to determine the electric charge (Q_r) and the vertical height to the charge center (H_r). To complete the record, the number of return strokes and duration were taken directly from the oscillograph readout for each recorded discharge.

We photographed the lightning discharges from a recording station with a 35-mm. camera operated by an electrostatic triggering device. This device is essentially a modified fast field change meter that produces a trigger pulse at the time of the discharge leader stroke. A counter is placed in front of the camera lens, providing a link between the photographs and the recorded field changes that correspond to them. Figure 1 is a composite of a lightning flash that started a forest fire on September 6, 1966, in western Montana (discharge number 4, table 1).

To document the effects of specific discharges upon forest fuels, we observed their ground terminals (usually trees) from a light aircraft flying near the storm. Upon seeing a nearby discharge, the aerial observer immediately transmitted a discharge identification number by radio to the lightning recording stations. His voice transmission was recorded on the same time-resolved magnetic tape that recorded the discharge, thus linking the aerial observation with its respective recording. The aircraft then circled in the immediate vicinity of the ground terminal and the observer attempted to locate it visually. If he was successful, he photographed the terminal (figure 2) and noted its location for subsequent on-the-ground study of lightning effects. Figure 3 shows the effects of the discharge characterized in figure 1.

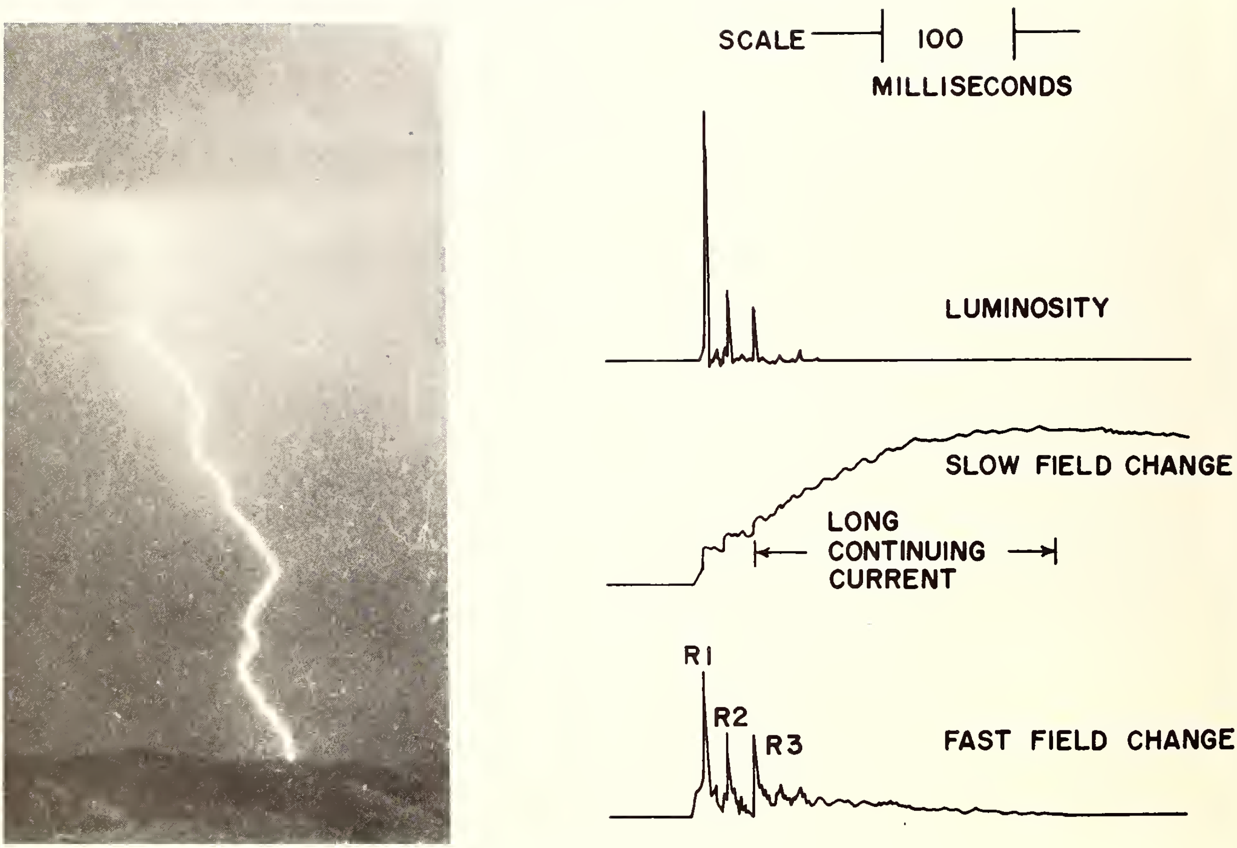

Figure 1.--Flash image, luminosity trace, and slow and fast field change traces of a discharge that caused a forest fire on September 6, 1966. Note the long-continuing current phase following the R3 stroke.

Figure 2.--Burning ground terminal photographed by aerial observer moments after lightning discharge was recorded at ground station 25 kilometers away.

Figure 3.--Effects of the lightning discharge recorded in figure 1. Ponderosa pine shows narrow cambium depth scar and charring on lower 1.5 meters of bole. Creeping surface fire had final perimeter of 40 meters.

RESULTS

Using the procedures described above, the aerial observer attempted to identify the ground terminals of 30 discharges observed in four storms during 1965 and 1966. He was able to identify seven of them. All seven ground terminals exhibited fire, and all the fires were caused by discharges having a long-continuing current phase as illustrated in figure 1. Characteristics of the discharges are given in table 1. Average value of the continuing current was 158 amperes over an average interval of 203 msec. Of the 856 cloud-to-ground discharges recorded during 1965 and 1966, about half had a long-continuing current phase.

Three of the seven fires required suppression, and four were extinguished through natural causes. We examined fire and structural lightning effects at four of the fires and found that (1) each of the fires involved at least one lightning-struck tree; (2) one showed ignition evidence in crown foliage and upper stem only, two showed both upper stem and ground fuel ignition, and one (figure 3) showed ground fuel and lower stem ignition; and (3) structural nonfire lightning damage to the tree stems ranged from minor bark loss on the least damaged (figure 3) to splitting and ejection of wood slabs from the stem of the most severely damaged tree.

These data support the hypothesis that lightning fires are caused by discharges having long-continuing currents. With refinement of the techniques described above, we expect to document more discharges and their effects during 1967.

Table 1.--Characteristics of seven lightning discharges causing forest fires

Discharge no. and date	Total charge	Number of return strokes	Continuing current phase		
			Duration	Charge	Mean current
	Coul.		Msec.	Coul.	Amps.
1. 7/4/65	40	2	235	29	125
2. 7/14/66	48	3	282	44	156
3. 9/6/66	76	3	243	55	225
4. 9/6/66	93	3	205	61	298
5. 9/6/66	22	2	228	19	85
6. 9/6/66	26	9	40	1	25
7. 9/14/66	42	3	190	36	189

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